Fuel Choice for Fuel Cell Vehicles: An Overview by the DOE Hydrogen Technical Advisory Panel May 1999

Introduction

Eight major automakers plan to commercialize fuel cell vehicles in the 2004-5 timeframe. All face the key issue of how to provide hydrogen to the fuel cells. They have two fuel choice options: either produce the hydrogen on the ground and then store it onboard the vehicle (the direct hydrogen option), or produce the hydrogen on the vehicle by means of a tiny onboard hydrogen plant (the onboard fuel processor option). Each option has multiple feedstock choices to produce the hydrogen. Onboard fuel processors can produce hydrogen from natural gas, methanol, ethanol, gasoline, or diesel stored onboard the vehicle. Ground-based hydrogen processors can also use all these feedstocks, and can also make hydrogen from the electrolysis of water.

For reasons associated with efficiency, technical difficulty, cost, and existing energy supply infrastructures, preferred feedstock choices for each fuel choice option have largely narrowed to gasoline or methanol for fuel cell vehicles with onboard fuel processors, and natural gas for direct hydrogen. For small hydrogen requirements, use of electricity for water electrolysis is also a choice for direct hydrogen. At this time, methanol appears to lead gasoline for onboard fuel processors due to better vehicle performance and lower technical difficulty, despite more costly changes needed to make methanol widely available at fueling stations. For direct hydrogen vehicles, the hydrogen can be stored onboard either as a compressed gas at about 5,000 psi, or as a cryogenic liquid.

Each option has advantages and disadvantages – relating to vehicle efficiency, technical difficulty, cost, fuel supply infrastructure requirements, safety, and long-term societal benefits. As discussed below, performance, technical difficulty, and societal benefits favor direct hydrogen. Costs on a per vehicle basis are comparable for both options. But due to concerns over fuel infrastructure requirements and, to a lessor extent safety, industry is strongly favoring the onboard processing option. (Nevertheless, it appears that both auto and energy companies are presently keeping their options somewhat open.)

Like industry, the federal government is providing substantially greater support for onboard fuel processing – *despite the significantly greater long-term societal benefits of direct hydrogen*. This is HTAP's concern, and the reason for this brief white paper.

Comparison of Fuel Choice Options

Recent, largely government-sponsored studies have clarified differences between the fuel choice options of direct hydrogen and onboard fuel processing for fuel cell vehicles – and are the basis for the qualitative comparisons that follow.

Efficiency and Technical Difficulty

Direct hydrogen vehicles are the most efficient, followed in order by vehicles with onboard methanol and gasoline fuel processors, with gasoline fuel processor vehicles being hardly more efficient than modern ICE vehicles. The added weight of the fuel processors and lower hydrogen content to the fuel cells cause the lower efficiencies. Fuel processor performance and its integration into the total vehicle system continue to present developmental challenges that are the focus of ongoing R&D work. Even after more immediate technical issues are solved, the greater complexity of fuel cell vehicles with onboard fuel processors creates long-term concerns over reliability and dependability. Technical difficulty is greater for gasoline than for methanol fuel processors, but the gasoline fuel processor has the virtue of being able to handle other fuels such as ethanol. This fuel flexibility is a key reason for DOE’s support of gasoline fuel processors.

Onboard storage of hydrogen as a compressed gas or liquid in sufficient quantities for acceptable vehicle range between refueling, and without loss of passenger or cargo space, requires no breakthroughs in hydrogen storage technology. Rather, it requires straightforward engineering development of onboard storage systems and of fueling station storage and compression systems. Gaseous storage seems more practical for passenger vehicles, with liquid hydrogen best suited for heavy duty fleet vehicles such as buses. Most desirable for direct hydrogen vehicles, would be storage of the hydrogen at low pressures and ambient temperatures as an adsorbed phase on a solid storage medium. Advanced carbon structures and possibly improved hydride materials offer such promise, but are still many years away from commercialization.

Cost and Fuel Supply Infrastructure

Simply put, on a cost per vehicle basis – which includes the vehicle cost and a portion of the fuel supply infrastructure allocated to each vehicle – the costs of direct hydrogen and onboard fuel processor fuel cell vehicles can be comparable after the vehicle population becomes large enough to amortize the cost of the refueling site.

Looking at fuel infrastructure costs on a per vehicle basis, however, begs the much larger issue of how a hydrogen fuel infrastructure could be created that initially serves the first few hundreds of fuel cell vehicles, then thousands and hundreds of thousands, and finally millions. This is direct hydrogen's "Achilles Heel". Past experience with other alternative fuel vehicles has demonstrated that it is very difficult to bring new infrastructure and vehicles to the marketplace at the same time – thus the attractiveness of the gasoline-fueled fuel cell vehicle with onboard an onboard processor. (Although, as research on the gasoline processor technology has progressed, it appears that a "special" gasoline might be required in order to achieve acceptable results.) Onboard methanol presents somewhat greater infrastructure difficulties, but its implementation seems much simpler than direct hydrogen.

It is much easier to envision hydrogen supply infrastructures for heavy-duty fuel cell fleet vehicles, based on a small number of central refueling stations with trained operators. A broad consensus exists that direct hydrogen is the logical choice for centrally fueled fleet vehicles. But fleet vehicles are not seen as a logical pathway to passenger vehicles.

Studies are beginning to paint the picture of how a hydrogen fuel infrastructure might evolve for passenger vehicles. Initially hydrogen could be produced and stored at the refueling stations by means of small on-site hydrogen generators, utilizing steam reforming or partial oxidation technology. While the preferred feedstock would be natural gas taken from the nation's existing natural gas distribution infrastructure, feedstocks such as methanol, ethanol, propane, or even gasoline could be used. In addition, water electrolysis units, connected to the nation's existing electricity infrastructure could supply smaller hydrogen requirements. (Thus direct hydrogen, in effect, represents the most flexible of fuel choices!) Hydrogen could be one of multiple fuels available at stations. As fuel usage grows to many thousands of vehicles, the picture might evolve to larger central plants, each delivering hydrogen to multiple stations by pipeline and/or liquid hydrogen tankers. Alternately, on-site hydrogen production may continue to prevail over the long term.

This picture, however, has many gaps. Small hydrogen generators (steam reformers, partial oxidation units, or electrolyzers) are not yet cost effective; further development work is needed. Clear, viable bridging strategies for direct hydrogen that can take us from the few initial vehicles to thousands of vehicles, while providing customers with acceptable refueling convenience and cost, continue to elude us. Use of the existing industrial hydrogen production and distribution infrastructure, co-production of hydrogen and electricity in future stationary fuel cell systems, and creation of regional fueling clusters and corridors, are possible bridging strategies under consideration. But we have a long way to go to convince carmakers and energy suppliers that direct hydrogen represents an early, viable pathway to eventual widespread usage of fuel cell vehicles.

One bridging strategy calls for onboard fuel processors *and* direct hydrogen vehicles to be marketed in series. Initially fuel cell vehicles with onboard processors would provide for initial market penetration. Upon widespread customer acceptance with many thousands of vehicles on the road sufficient volume would exist to economically justify a transition to direct hydrogen vehicles. Optimistically, such a transition might take place within a decade. This is an attractive scenario, but it may be flawed. Once the onboard processor option achieves market dominance, it could lock out direct hydrogen vehicles for many decades to come– thus denying society the superior long-term benefits of direct hydrogen vehicles (these benefits are enumerated below). Witness the long-term market dominance of other inferior technologies over their rivals: for example, VHS over Beta in the VCR market, and Windows over Macintosh in the PC market.

<u>Safety</u>

Hydrogen advocates often characterize the issue of hydrogen safety as one of perception only, stating that hydrogen is intrinsically safer than many other fuels, including gasoline and natural gas, and pointing to the excellent safety record of the merchant hydrogen industry. Safety is not just a perception; it is a *real* issue! However, it is a *manageable* issue. With sufficient attention to R&D, engineering development and design, and codes and standards development, acceptance by the insurance industry and the public will follow.

<u>Societal Benefits of Direct Hydrogen</u>

Societal benefits strongly favor direct hydrogen. Higher efficiency for direct hydrogen directly translates to lower emissions – of both pollutants and greenhouse gases. (Although HTAP recognizes that the onboard fuel processor option, even with gasoline, represents a major advance in reduction of pollutants over conventional ICE vehicles.)

Direct hydrogen decouples energy sources from the vehicles themselves, and thus provides for maximum fuel flexibility, both near and long term. In the near term, it allows for use of the nation’s abundant domestic natural gas supply, and possibly its electrical grid, while still leaving the door open to methanol, ethanol, gasoline, and diesel. In the longer term, it allows for entry of renewable energy – biomass, solar, wind, and hydro – into the hydrogen supply infrastructure. (Methanol and ethanol also provide pathways to renewable energy, but are less versatile.) Decoupling allows for use of different energy and fuel sources in different regions of the country, depending on economics and energy availability. It also allows developing countries to take unique, advantageous pathways to the introduction of fuel cell vehicles, as a function of domestic energy sources and pollution mitigation goals, thus avoiding the need to import more expensive fuels.

In the case of gasoline fueled fuel cell vehicles, direct hydrogen naturally reduces the nation's dependence on imported oil.

Finally, direct hydrogen leaves the door open to the possibility of eventual carbon removal and sequestration from fossil fuels used to power fuel cell vehicles. Long-term use of onboard fuel processors forever closes that door, since it is totally impractical to separate and sequester carbon dioxide from the emissions of such vehicles.

Conclusion: An Appropriate Role for Government

The Department of Energy's Comprehensive National Energy Strategy (April 1998) states: "The basic energy policy of the United Stated in recent years has been to rely on markets to allocate most resources with selective government intervention to ensure that certain highly valued societal needs – including the need for energy security, environmental quality, and energy research – are met."

HTAP agrees with DOE's R&D support for fuel cell vehicles with onboard fuel processors. Widespread implementation of fuel cell vehicles, even with onboard fuel processors, will provide important societal benefits – and onboard fuel processors may turn out to be the most feasible means of making fuel cell passenger vehicles a reality. HTAP is concerned, however, over DOE's current approach of giving substantially more support for the onboard fuel processor option – the option strongly supported by industry, and the option yielding substantially fewer societal benefits in the long run. This approach seems inconsistent with the Comprehensive National Energy Strategy.

A more balanced allocation of DOE R&D resources between the two fuel cell vehicle options would increase the chance of success for timely implementation of direct hydrogen fuel cell vehicles. How might increased funding for direct hydrogen be used? Here is a very preliminary list. A more definitive list would need input from both DOE and industry.

- Expand system studies of refueling scenarios, with a major goal of identifying viable bridging strategies between initial introduction and widespread implementation. Industry needs to be involved in a major way in such studies. (HTAP has decided to stress fuel cell vehicle scenarios as part of the planned work of its new Scenario Planning Committee.)

- Expand R&D of advanced hydrogen storage technologies that hold the promise of storing substantial quantities of onboard hydrogen at low pressure and ambient temperature – for example materials based on carbon nanotubes, aluminum silicate polyhydrides, and advanced hydrides. Participation by the Office of Science would be a major plus.

- Expand the R&D work on onboard fuel processors to consider dual uses for both onboard and, at a larger scale, for ground-based fuel processors that generate hydrogen at fueling stations.

- Expand ongoing work on hydrogen safety R&D and codes and standards development. For example, more R&D is needed on hydrogen and flame sensors, flame arrestors, and excess flow valves. Vehicle and fueling station demonstrations, while not a pathway to widespread fuel cell vehicle implementation, serve as valuable precedences for safety, codes and standards, and insurance availability.

- In our Report to Congress, HTAP recommended that new alternative fueled vehicle legislation give extra consideration for direct hydrogen fuel cell vehicles, in terms of incentives and mandates, commensurate with direct hydrogen’s greater societal benefits. Included is a suggestion that new federal vehicle fleet vehicles at federal facilities which already use hydrogen, such as NASA and Air Force aerospace launch and test facilities, be hydrogen fueled.

- Finally, while it is not direct hydrogen, HTAP supports ongoing R&D work on direct methanol fuel cells, that electrochemically react methanol to carbon dioxide and water without need to first produce hydrogen. If direct methanol fuel cell technology can eventually overcome problems such as low efficiency and scale-up to vehicle fuel cell sizes, they can provide significant societal benefits, especially when the methanol is produced from renewable sources.

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